myocardial infarction reduces total high frequency voltage.[17-19] We have also found contrary to classic ECG theory that the number of low amplitude QRS notches actually correlates inversely with total high frequency content. Reduction of high frequency voltage following myocardial infarction probably reflects an overall decrease in electromotive force and possibly also slowing of conduction. At present, studies are underway to see if such quantitative high frequency measurements can increase the diagnostic accuracy of the conventional ECG.

DR. FROELICHER: *The application of microprocessor technology to electrocardiography will lead to exciting advances in health care. The system that we have been using has the computer power of a system that 15 years ago would almost have filled a room; now it is all contained within a standard three-channel* ECG *machine. The previous use of high frequency electrocardiography was limited by problems with interference and expensive equipment. Also, it was difficult to acquire and store the signals because of the excessive signal-to-noise ratio. All these problems are circumvented with this system. Dr. Goldberger plans to continue his work with this system and evaluate surface bundle of His spikes and early repolarization.*

Dr. Tubau will next summarize his experience at the Montreal Heart Institute with the use of multiple ECG *leads during exercise testing in patients with and without previous myocardial infarction. We are very happy to have Dr. Tubau at* UCSD *as a research cardiologist in the Nuclear Medicine Department, working with Dr. Ashburn.*

Exercise Testing With Multiple Leads in Patients With and Without Previous Myocardial Infarction

JULIO F. TUBAU, MD

A MAJOR QUESTION in exercise testing has been how many electrocardiographic leads are needed for the optimal detection of coronary heart disease? Attempts at improving accuracy have been made using multiple leads,[20] different criteria for a positive test[21] and computer analysis of the electrocardiogram.[22,23] The importance of prevalence and the extent of coronary disease have been found to have a serious impact upon the predictive value and sensitivity of exercise ECG's.[24,25] Since prevalence of coronary heart disease is related to clinical presentation, evaluation of exercise ECG's should consider patients in different categories of symptoms and clinical presentations. For the purpose of this discussion, patients have been classified as those with typical angina, those with probable angina and those with symptoms of atypical or nonischemic chest pain. Existence of a previous myocardial infarction is obviously associated with a high prevalence of coronary heart disease.[26] Exercise testing is used in this group of patients to detect occlusive disease in other vessels than the one related to the myocardial infarction.

This section will review the usefulness of a comprehensive approach to exercise testing with multiple leads in two populations: first, 200 consecutively seen male patients without previous myocardial infarction with a normal resting electrocardiogram; second, 118 men surviving a transmural myocardial infarction.

Methods

Patients exercised on a treadmill following a modified Bruce protocol.[27] The electrocardiogram obtained consisted of 14 leads including the standard 11 but excluding AVR and bipolar leads CC_5, CM_5 and ML (ML was formed by electrodes placed on the manubrium and the flank). Criteria for a positive test were horizontal or down sloping ST segment depression more than 0.1 millivolt for 0.08 second or an ST segment slowly upsloping with depression more than 0.2 mV at 80 msec after the J-point.[21] All negative tests had to exceed at least 85 percent of the age-predicted maximal heart rate to be considered maximal. Coronary angiography was carried out the day after the exercise test. Selective coronary arteriography was done using a percutaneous technique.[28] A lesion greater than 70 percent of the arterial luminal diameter was considered significant except for the left main coronary artery where stenosis equal to or greater than 50 percent was considered significant. Left ventricular wall motion was assessed qualitatively by an experi-

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TABLE 1.—*Diagnostic Values of Exercise Testing in Different Clinical Subsets*

Clinical Subsets	*Lead System* V_5	CM_5	CC_5-CM_5-ML	$14L$
Typical or probable angina (N=151)				
Sensitivity	0.61	0.74	0.83	0.85
Specificity	0.91	0.77	0.76	0.76
Likelihood ratio (+)	6.78	3.08	3.46	3.58
Likelihood ratio (−)	2.33	2.92	4.47	5.43
Atypical chest pain (N=49)				
Sensitivity	0.50	0.57	0.64	0.64
Specificity	0.86	0.74	0.69	0.69
Likelihood ratio (+)	3.57	2.19	2.07	2.07
Likelihood ratio (−)	1.72	1.72	1.92	1.92

enced radiologist and recorded as normal, hypokinetic, akinetic and dyskinetic.

Coronary Artery Disease Without Previous Myocardial Infarction

Symptoms

The 87 patients presenting with typical angina had an 86 percent prevalence of coronary heart disease, the 64 with probable angina had a prevalence of angiographic disease of 65 percent, and of 49 with nonspecific chest pain 28 percent had disease. The severity and distribution of coronary stenosis were similar in patients with typical or probable angina but much less severe in patients with atypical symptoms. Fewer patients in this latter subset had three-vessel disease or proximal left anterior descending stenosis (7 percent versus 32 percent and 7 percent versus 34 percent, respectively—$P=0.05$). Symptoms were clearly related to the severity of the lesions.

Multiple Versus Single Leads

Sensitivity increased using multilead systems in all subsets of patients with only a minor reduction in specificity. The efficiency of the test—that is, the percent of patients correctly classified—increased when multiple leads were used in patients with typical and probable angina but decreased in patients with atypical symptoms because of an increase in false-positive results. Three-vessel disease and left main disease were better detected in patients with typical and probable angina using the 14 leads. The combination of ST segment depression and total treadmill time was better able to separate patients with severe coronary artery stenosis, particularly in subsets other than those with atypical chest pain. For instance, a positive test with the 14 leads and a total treadmill time less than or equal to six minutes detected 58 percent of patients with three-vessel disease and 86 percent of patients with multivessel disease. Conversely, a negative exercise test going into Bruce stage III (greater than nine minutes) in patients with typical or probable angina was associated with only 15 percent having multivessel disease and 5 percent with three-vessel or proximal left coronary disease. Patients with nonspecific chest pain were less benefited by this combination.

Because sensitivity and specificity were different for the patients with typical and probable angina compared with those with nonspecific chest pain, the likelihood ratios (LR)—the numerical value of the probability that a given test result is a true one versus a false one—were also different for the two groups of patients (Table 1). The ratio of an abnormal test is calculated by the formula: likelihood ratio (+) = sensitivity divided by one minus specificity. The use of this value in calculating the posttest risk of disease is exemplified by the following formula: Posttest risk of disease = pretest risk (prevalence) × LR(+). Since LR+ was lower for each lead system in the patients with nonspecific chest pain compared with more symptomatic patients, the calculation of posttest probability of disease may be incorrect using a single value of likelihood ratio for all patients; that is, since sensitivity and specificity change in populations with different prevalences of disease, likelihood ratios change.

In conclusion, exercise testing with multiple leads in subsets without previous myocardial infarction has its major contribution in patients with typical or probable angina. The combination of ST segment depression and treadmill time was useful for separating patients with and without multivessel disease or high-risk lesions. It is clear that predictive statements of the posttest risk of disease must be used carefully since their accuracy will depend upon the similarity between the populations actually examined and the population from which sensitivity and specificity values were derived.

Multivessel Disease and Previous Transmural Myocardial Infarction

We carried out studies in 118 men who survived a transmural myocardial infarction. The acute infarction occurred within a year in 75 percent of the patients. The other patients had silent infarctions or had a longer interval between infarction and subsequent coronary angiography but were similar to the entire group in regard to symptoms, electrocardiogram and angiographic data. The severity of the angina was classified according to the Canadian Cardiovascular Classification[30] (asymptomatic = 0; the presence of angina was coded as 1, 2 or 3 as to its occurrence during mild, ordinary or strenuous exertion, respectively).

Inferior Versus Anterior Infarction

The prevalence of multivessel disease in patients with *inferior myocardial infarction* was 68 percent. Of patients with mild symptoms (group A), 50 percent had multivessel disease compared with 80 percent of those with more symptoms (group B). When there were abnormal findings on an exercise ECG using 14 leads, 80 percent of patients with mild symptoms (group A) and 96 percent of those with severe symptoms (group B) were found to have multivessel disease. With a test showing no abnormalities, only 20 percent of group A patients and 56 percent of group B patients ($P = 0.05$) had multivessel disease. The prevalence of high-risk lesions (three-vessel and proximal left coronary artery stenosis) was 13 percent in group A patients, and a combination of abnormal findings on an ECG test and final treadmill time selected 60 percent of patients with that condition. A test showing no abnormalities was associated with that severe disease in only 4 percent of the cases. Thus, an exercise test is more useful in patients with few or no symptoms after an inferior myocardial infarction.

Patients with a previous *anterior myocardial infarction* had a 58 percent prevalence of multivessel disease. The extent and prevalence of multivessel disease did not correlate with angina class. The sensitivity of a 14-lead ECG was less for patients with anterior infarctions (64 percent) compared with inferior myocardial infarction (76 percent). Similarly to the inferior infarct patients, the maximum diagnostic information occurred in those with mild coronary symptoms (group A). An abnormal result of an exercise ECG detected 86 percent of patients with multivessel disease and a negative response excluded this condition in 70 percent of the cases. When considering depth of ST segment depression and total treadmill time it was possible to obtain additional information. A normal test finding in the 14-lead study through Bruce stage III decreased the probability of three-vessel disease to 10 percent. A positive test with equal to or greater than 0.2 mV of ST segment depression and a final treadmill time less than six minutes increased the likelihood of three-vessel coronary disease to 64 percent. Survivors of an anterior myocardial infarction presenting with more severe symptoms benefited less from exercise testing.

TABLE 2.—*Detection of Multivessel Disease After Transmural Myocardial Infarction (MI)*

	Lead System		
Infarction Location	V_5	CC_5-CM_5-ML	14L
Inferior MI (N=75)			
Sensitivity	0.22	0.69	0.77
Specificity	0.96	0.88	0.79
Anterior MI (N=43)			
Sensitivity	0.4	0.56	0.64
Specificity	1.0	0.83	0.67

ST Segment Elevation

Isolated ST segment elevation was associated with the corresponding akinetic or dyskinetic wall motion abnormality in 92 percent of the cases. The inclusion of ST segment elevation in the criteria for positivity did not augment the sensitivity of the test.

Chest Pain

The presence of angina during exercise testing by itself was a powerful predictor of multivessel disease. Of 45 patients with this finding, 40 had multivessel disease. The absence of angina during the test did not exclude multivessel disease because 50 percent of the patients without angina had this disease.

Choice of Lead Systems

The utilization of multilead systems increased sensitivity with a slight decrease in specificity (see Table 2). Overall, these findings suggest that a combination of V_5 and two bipolar leads (CC_5 and CM_5), in addition to being simpler, provides similar predictive information with only an 8 percent decrease in sensitivity compared with the 14 leads. This latter study was obtained in a selected population which excluded nontransmural myocardial infarction and may not be generally applicable for all those who have had a myocardial infarction.

Conclusions

These studies show that the modern approach to exercise testing takes into account symptoms before interpreting exercise ECG results. The electrocardiographic response must be weighed differently depending upon the pretest risk of disease.

Second, interpreting exercise test results must include other variables in addition to just abnormal ST segment depression. For example, the depth of ST segment depression and treadmill time provide valuable diagnostic information.

DR. FROELICHER: *The work from the Montreal Heart Institute has been very valuable in applying Bayesian statistics and the predictive model to clinical exercise testing. Dr. Tubau has excellently summarized this. V_5 or a similar left precordial lead is the most sensitive and may be all that is necessary in patients with a normal resting* ECG *and without a history compatible with coronary artery spasm or myocardial infarction. Anterior, lateral and inferior leads are essential in patients with abnormal* ECG*'s, an old myocardial infarct or a history compatible with spasm.*

Dr. Costello and Dr. Glover will now present a summary of the use of two-dimensional echocardiography in evaluating coronary heart disease.

Two-Dimensional Echocardiography

DENNIS COSTELLO, MD
MATTHEW GLOVER, MD

ULTRASONIC METHODS have been used to study the structure and function of the heart in health and disease since Edler and Hertz[31] in 1954 first recorded the motion of the mitral valve and posterior left ventricular wall by M-mode techniques. In the last decade M-mode echocardiography has provided accurate and relatively inexpensive diagnostic and serial follow-up information on patients with congenital, valvular, pericardial and myopathic heart disease.

The M-mode technique additionally has been widely employed as a means of determining the size and function of the left ventricle. Various investigators[32-35] have shown an excellent correlation between echocardiographic and angiographic left ventricular volume and ejection fraction. Such calculations of left ventricular size and function assume that the internal diameter of the left ventricle obtained by the single beam of the M-mode technique was representative of the contraction pattern of the left ventricle as a whole. In patients with coronary artery disease and previous myocardial infarction, asymmetry of contraction commonly is seen, and thus this single view obtained by the M-mode echo may not be representative of the entire left ventricular contraction pattern. Teichholz has clearly shown the limitations of such volume and ejection fraction determinations in patients with coronary artery disease and asymmetry of contraction.[36]

Such limitations of quantitative evaluations of left ventricular performance with one-dimensional ultrasonic techniques prompted increased interest in two-dimensional methods. Such methods would allow for special orientation of the heart with real-time viewing of the entire left ventricular silhouette including areas of left ventricular asynergy. The initial two-dimensional studies employed B-mode scanning techniques and were moderately successful,[37] although difficulties with tangential views, arrhythmias and chest and transducer motions tended to distort the cardiac silhouette.[38]

Equipment and Recording Techniques

The two commonly employed devices for obtaining two-dimensional images are the mechanical arc sector scanner[39] and the phase-array scanner.[40,41] The mechanical scanner uses a single beam which is swept mechanically through a given arc by a small motor. The phase-array scanner uses an electronic beam guided over an 80° arc.

Studies are carried out with patients in the supine or left lateral decubitus position. A complete two-dimensional examination includes long- and short-axis views obtained with the transducer in the parasternal position and apical two- and four-chamber apical views as previously described[42] (Figures 6 and 7). Suprasternal notch placement of the transducer may also be used for long-axis viewing.[43] Such views provide for

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